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Alumina Based 500°C Electronic Packaging Systems and Future Development

(Invited)

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Abstract

NASA space and aeronautical missions for probing the inner solar planets as well as for in situ monitoring and control of next-generation aeronautical engines require high-temperature environment operable sensors and electronics. A 96% aluminum oxide and Au thick-film metallization based packaging system including chip-level packages, printed circuit board, and edge-connector is in development for high temperature SiC electronics. An electronic packaging system based on this material system was successfully tested and demonstrated with SiC electronics at 500°C for over 10,000 hours in laboratory conditions previously. In addition to the tests in laboratory environments, this packaging system has more recently been tested with a SiC junction field effect transistor (JFET) on low earth orbit through the NASA Materials on the International Space Station Experiment 7 (MISSE7). A SiC JFET with a packaging system composed of a 96% alumina chip-level package and an alumina printed circuit board mounted on a data acquisition circuit board was launched as a part of the MISSE7 suite to International Space Station via a Shuttle mission and tested on the orbit for eighteen months. A summary of results of tests in both laboratory and space environments will be presented. The future development of alumina based high temperature packaging using co-fired material systems for improved performance at high temperature and more feasible mass production will also be discussed.

Alumina Based 500°C Electronic Packaging Systems and Future Development

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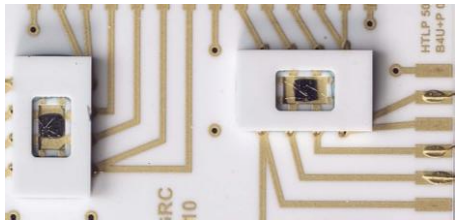
Outline

Background

- 500°C SiC electronics and sensors
- 96% alumina and thick-film metallization based packaging system for 500°C applications

Review of laboratory test results of 96% alumina packaging system for 500°C SiC electronics and sensors



Space and flight test of 96% alumina based high temperature packaging system

Future development of alumina based high temperature packaging system using co-fired alumina systems

Summary

Alumina Based 500°C Electronic Packaging Systems and Future Development

Background

500°C SiC electronics and MEMS sensors have been demonstrated

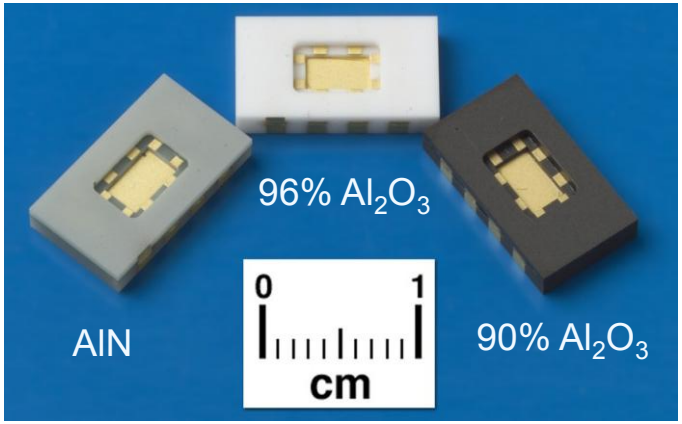
- JFETs and JFETs based circuits demonstrated at NASA GRC
- MEMS based pressure sensors and Schottky diode based gas chemical sensors developed at NASA GRC
- Applications include aerospace engine control and long term Venus probes

96% alumina and thick-film metallization based prototype packaging system in development for 500°C SiC electronics and sensors

- 96% alumina provides acceptable electric/dielectric properties at high temperatures up to 550°C
- The system composed of chip-level package, printed circuit board (PCB), and edge-connector (in development)

96% alumina packaging system

Ceramic Chip-level Packages and PCBs



- Three types of ceramics and Au thick-film metallization based chip-level packages and printed circuit boards (PCBs)
- Chip-level packages characterized between room temperature and 500°C
- An edge connector in development for PCB – PCB (subsystem-level) interconnection
- 96% alumina provides best electrical performance at high temperatures

Chen and Hunter, 2005 HiTEN

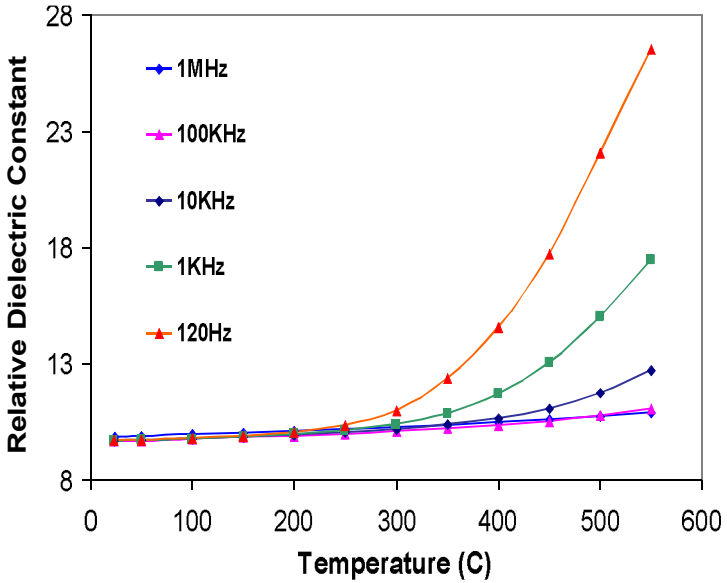
96% alumina packaging system – Laboratory test

Performance of 96% Alumina Substrate

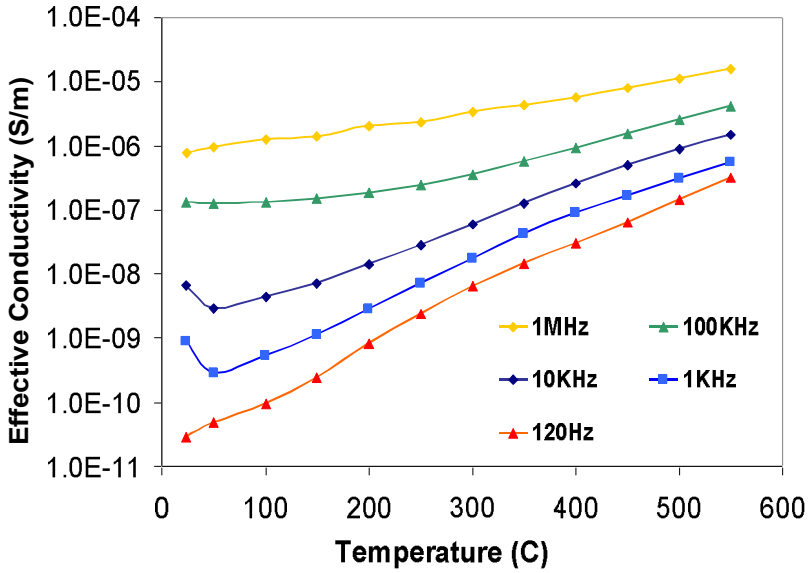
Required dielectric properties of substrate materials at high temperature

- Stable and low dielectric constant at elevated temperatures
- Low dielectric loss at elevated temperatures

Dielectric Constant of 96% Al_2O_3



AC Conductivity of 96% Al_2O_3



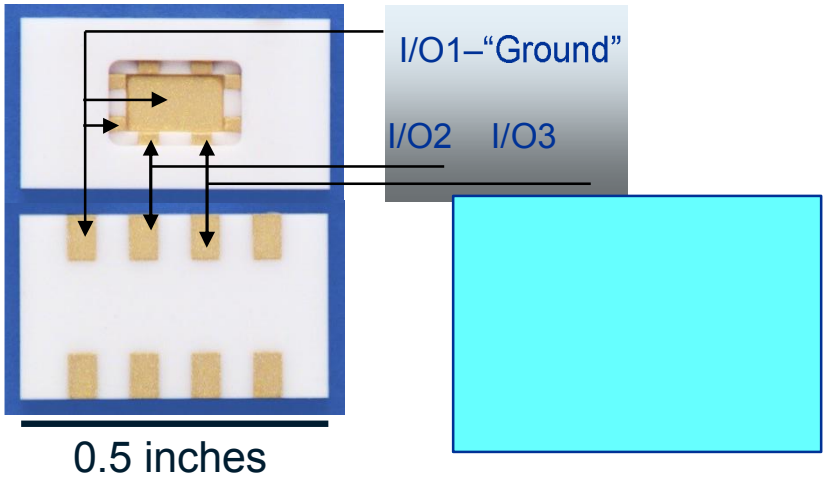
- The challenge for 500°C packaging technologies is at the materials level
- Compared with other alumina substrate materials tested, 96% alumina has better dielectric performance at high temperatures

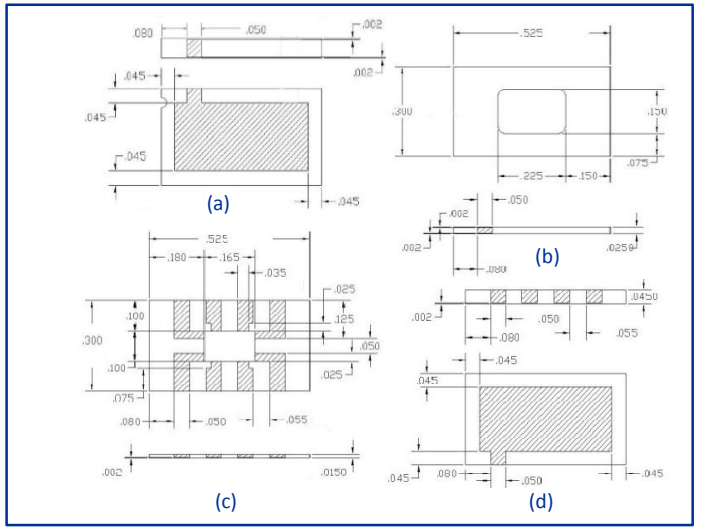
Chen, 2007 icept

96% alumina packaging system Laboratory test

96% Alumina Chip-level Packages

Chen and Hunter, 2005 HiTEN





Parasitic Capacitance and Conductance of Neighboring I/Os

T (°C) / f (Hz)	T_R	100	150	200	250	300	350	400	450	500	550
100	0.00nF	0.00nf	0.00nF	0.00nF	0.00nF	0.00nF	0.00nF	0.00nF	0.00nF	< 5	5
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.005	0.00	0.00
120	0.5	0.5	0.5	1	1	1	1.5	1.5	1.5	1.5	2
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0005	0.001	0.001
1K	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.7	0.8	0.95
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.0025
10K	0.49	0.50	0.50	0.490	0.49	0.52	0.53	0.58	0.59	0.65	0.69
	0.001	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.006	0.008
100K	0.492	0.486	0.497	0.493	0.487	0.517	0.539	0.535	0.563	0.585	0.57
	0.005	0.006	0.0015	0.002	0.003	0.005	0.007	0.011	0.015	0.022	0.030
1M	0.501	0.497	0.485	0.506	0.499	0.529	0.533	0.55	0.556	0.544	0.55
	-	-	-	-	-	-	-	-	-	-	-

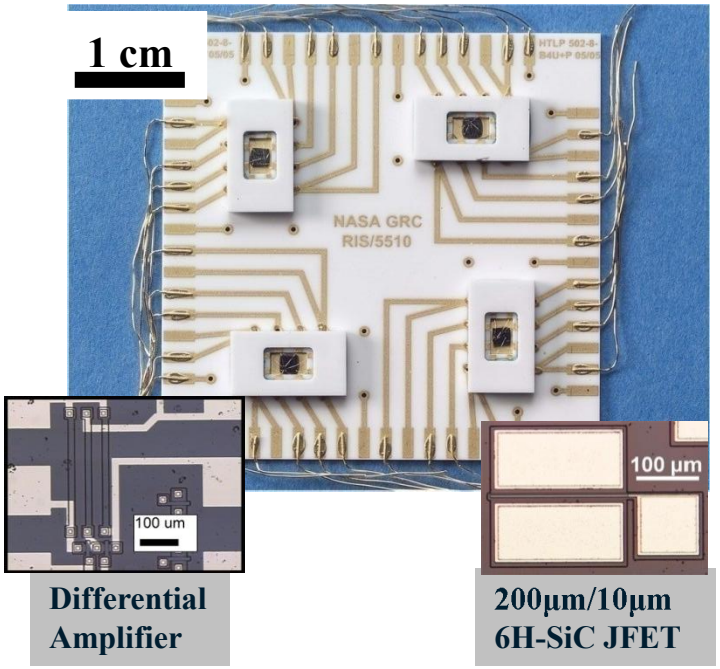
Usable for packaging many envisioned low power 500°C devices/ circuits

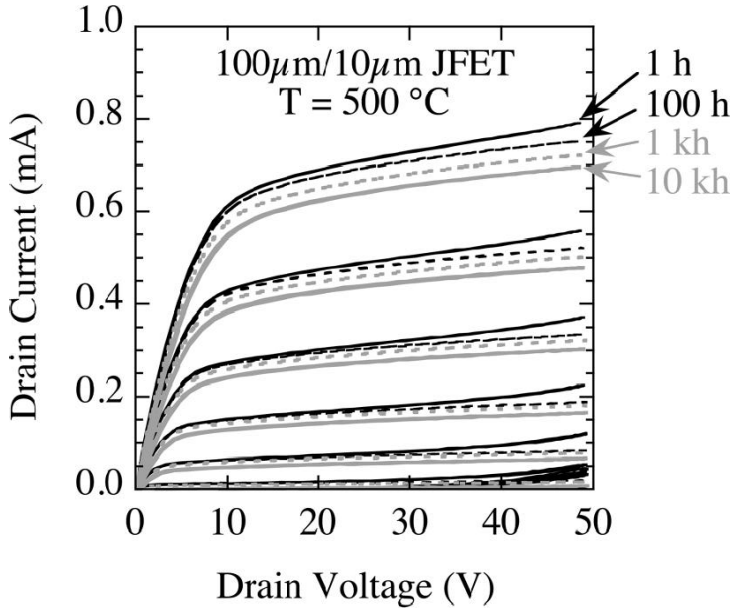
> 50°C margin above 500°C

pF
µS

96% alumina packaging system - Laboratory test

Static Thermal Test



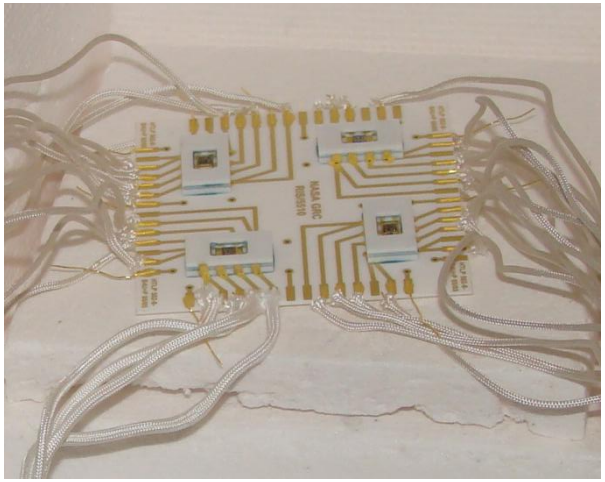


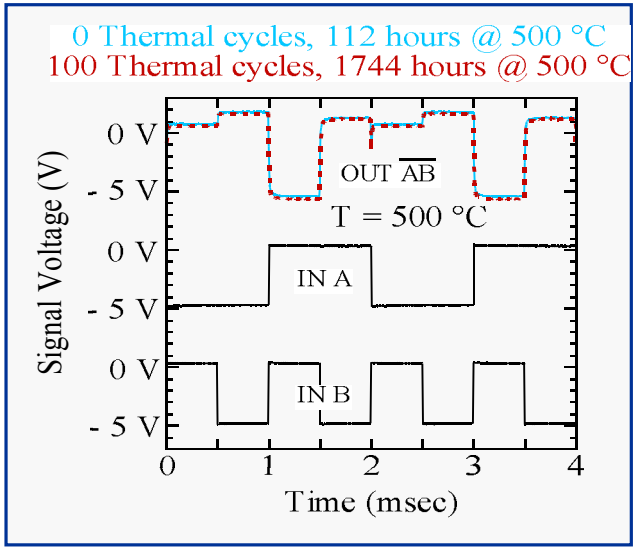
Neudeck, Spry, *et al*, 2008 ECSCRM

- 96% alumina packaging system – chip-level packages and PCB
- less than 7% change in the JFET characteristics in first 6000 hours
- Tested at 500°C for over 10,000 hrs
- Demonstrated for long term operation at 500°C for the first time

96% alumina packaging system - Laboratory test

Dynamic Thermal Test





- 96% Alumina substrate and Au thick film metallization based chip-level packages and PCB
- Four SiC chips on the circuit board
- $T_R \leq T \leq 500^oC$
- 40^oC/min up ramp and cooling in air

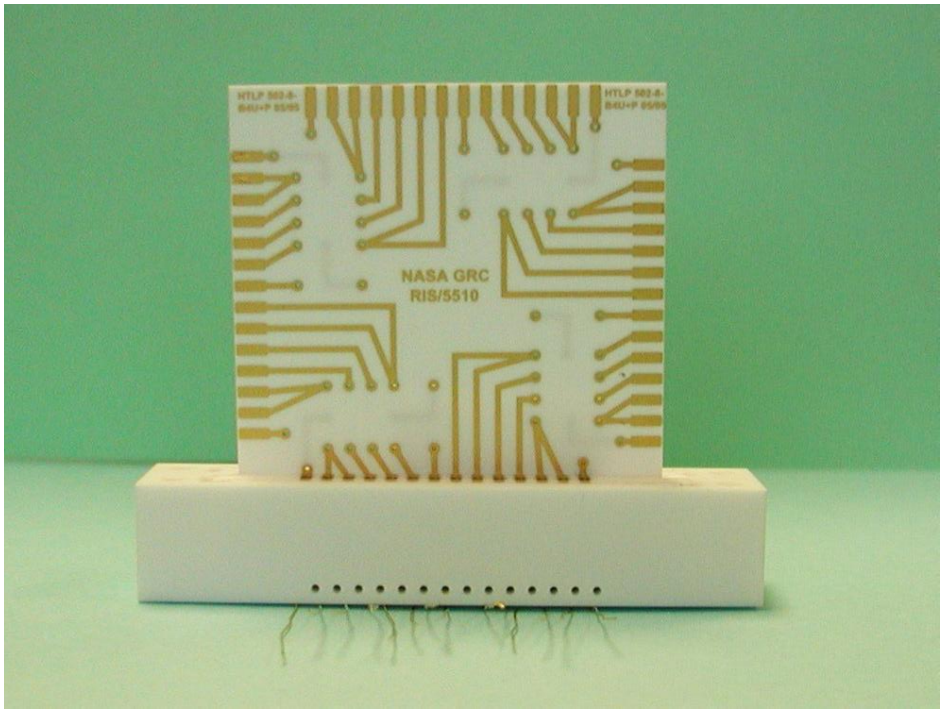
- SiC JFETs based NAND logic gate
- 1744 accumulated hours at 500 ^oC
- Before and after 100 cycles
- No packaging degradation/failure observed

Neudeck *et al*, Phys. Status Solidi. A, 2009, and Proceedings of 220th ECS, 2011

96% alumina packaging system - Laboratory test

PCB Edge Connector for 500°C Low Power Electronics

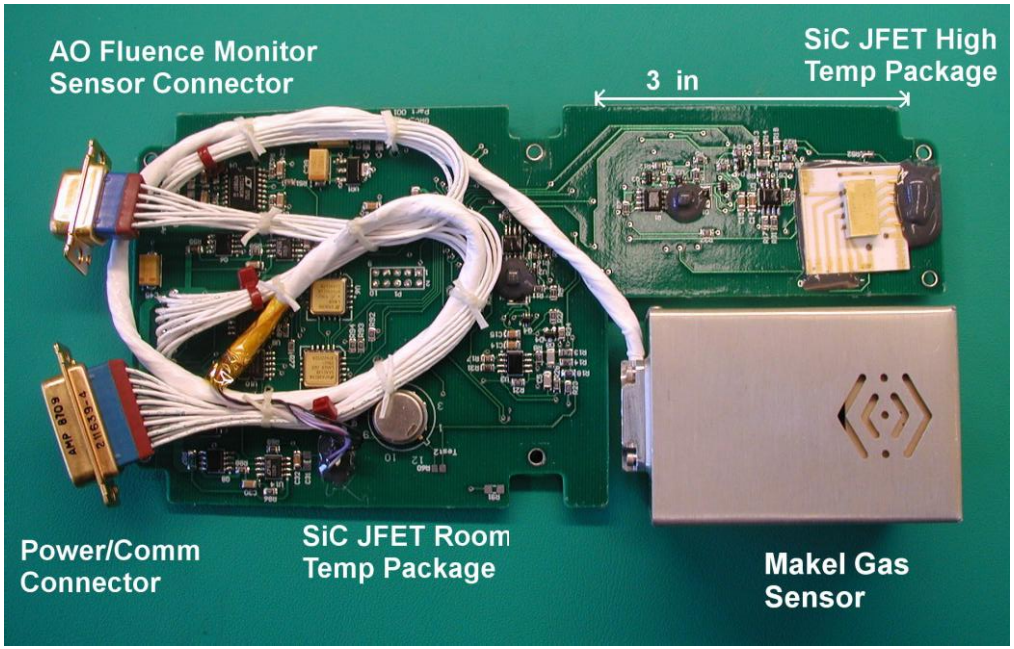
- Subsystem Level Interconnection



- PCB level interconnection
- For 500°C operation
- 96% alumina structure
- High temperature thick-film metallization
- 15 mil Au wires with fiber insulation sleeves
- High temperature alloy springs for electrical contacts
- In development and test

96% alumina packaging system – Space and flight test

Space and Flight Test of 96% Alumina Packaging System

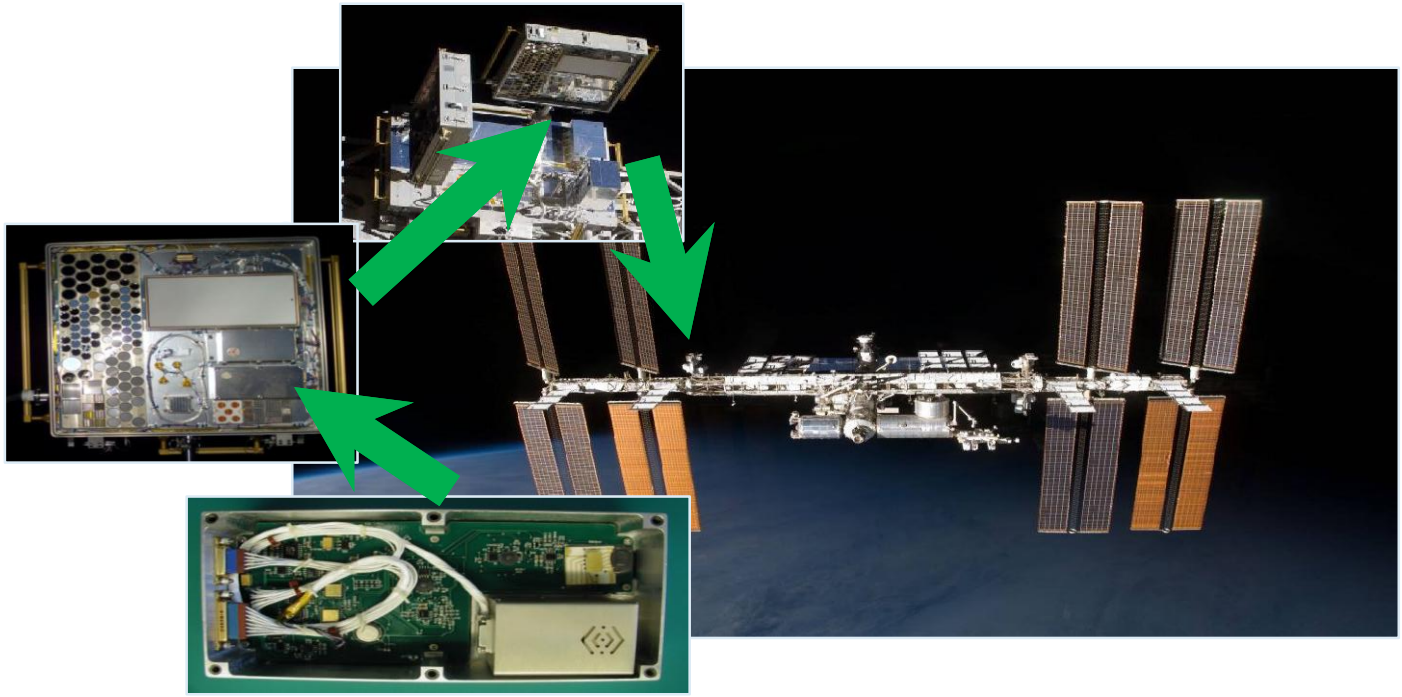


- 96% alumina chip-level packaging, PCB, and joining materials
- First flight and space test of 96% alumina high temperature harsh environment packaging system
- Monitor packaged SiC JFET DC parameter and compare with a SiC JFET in a conventional package

Prokop et al, 2010 National Space & Missile Materials Symposium

96% alumina packaging system – Space and flight test

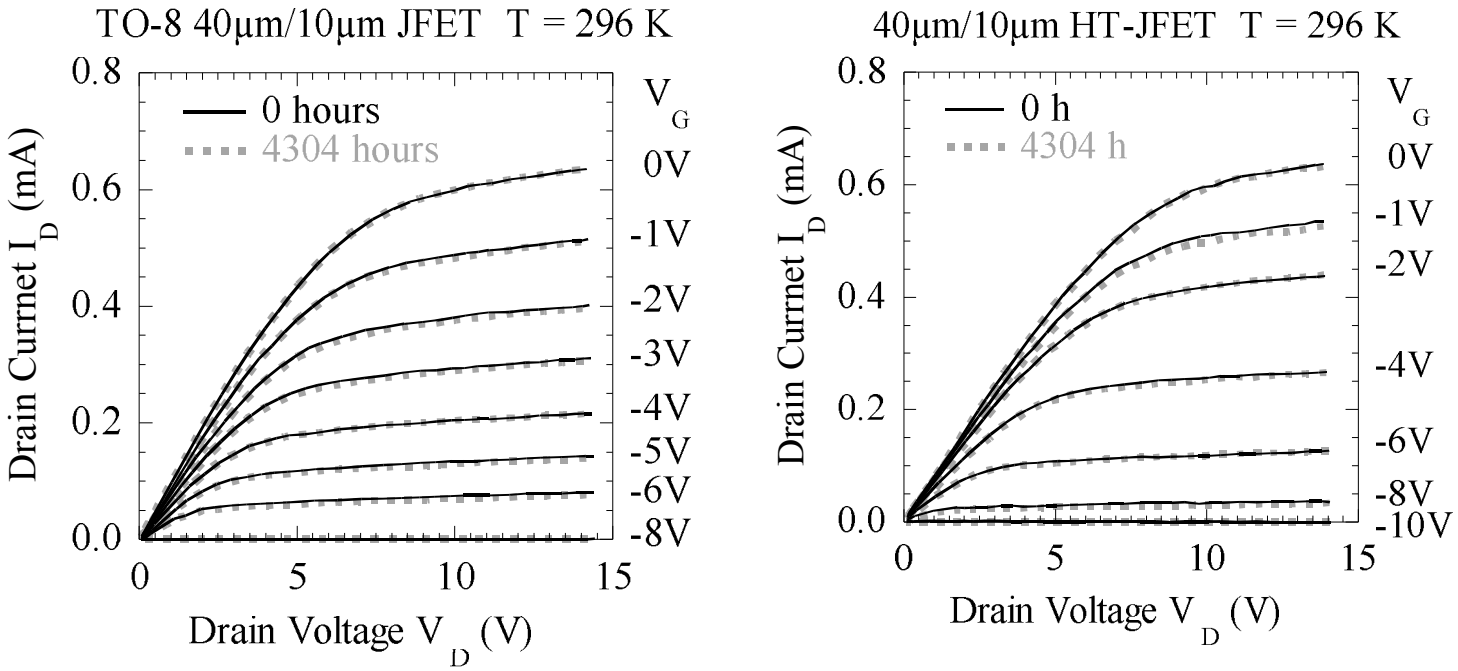
Space and Flight Test of 96% Alumina Packaging System



- MISSE7 suite exposed to Shuttle launch, atomic oxygen, space radiation, thermal cycling, and reentry
- In an aluminum box
- Eighteen months on ISS orbit

96% alumina packaging system Space and flight test

On-orbit I-V Data of Packaged SiC JFETs



- I-V data acquired every hour with temperature measurement
- Eighteen months on orbit
- Latest Set of V_{DS} vs. I_D curves shows no degradation
- No packaging degradation/failure detected after space and flight tests

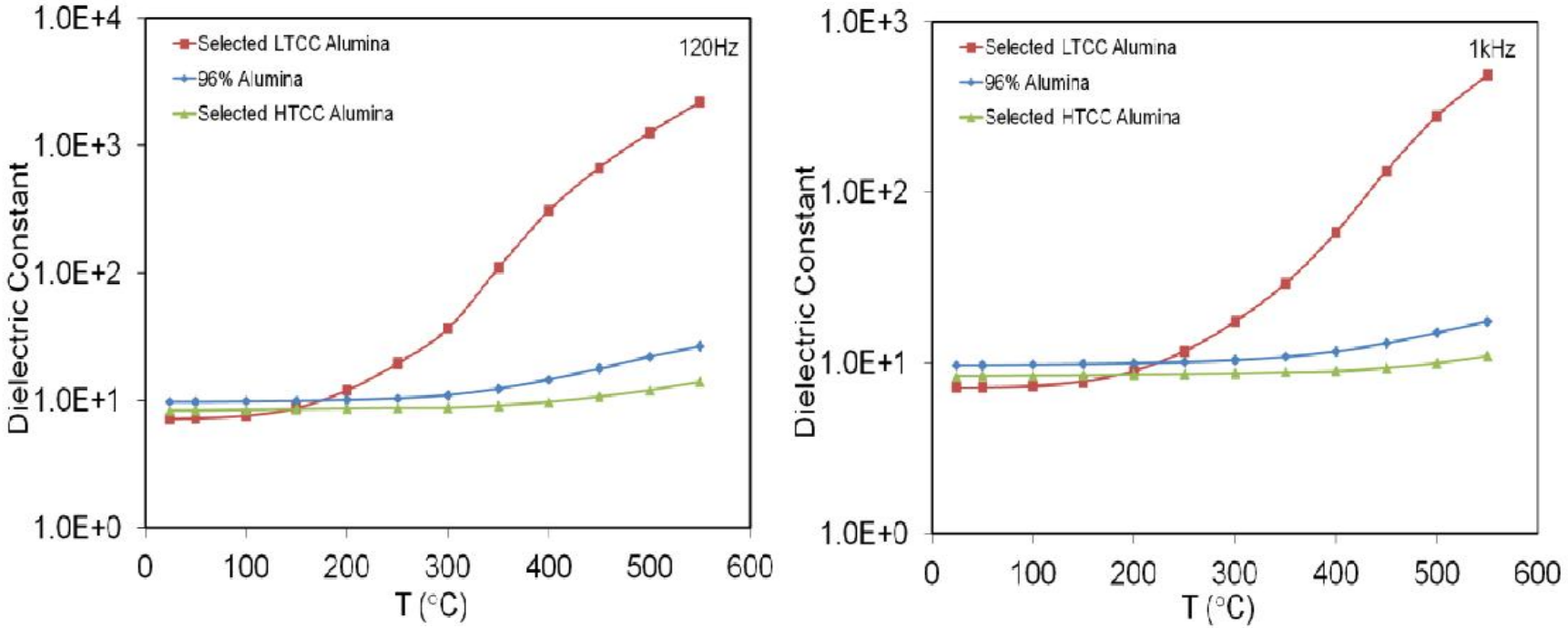
Prokop et al, 2010 National Space & Missile Materials Symposium

LTCC and HTCC Alumina

- 96% alumina substrate based packaging system
  - Dielectric properties of 96% alumina measured at temperatures up to 550°C
  - Excellent electrical and dielectric properties as substrate for conventional electronics
  - Thin-film and thick-film metallization available
  - 96% alumina packaging system long term tested with SiC electronics at 500°C
  - Chip-level packages not fabricated with co-fired process

- Low temperature and high temperature co-fired (LTCC and HTCC) alumina substrates ?
  - A few percent of glass used in co-fired alumina systems
  - Suitable for large scale commercialization
  - Dielectric performance at high temperatures?
  - Metallization scheme?

Future development of alumina high temperature packaging systems



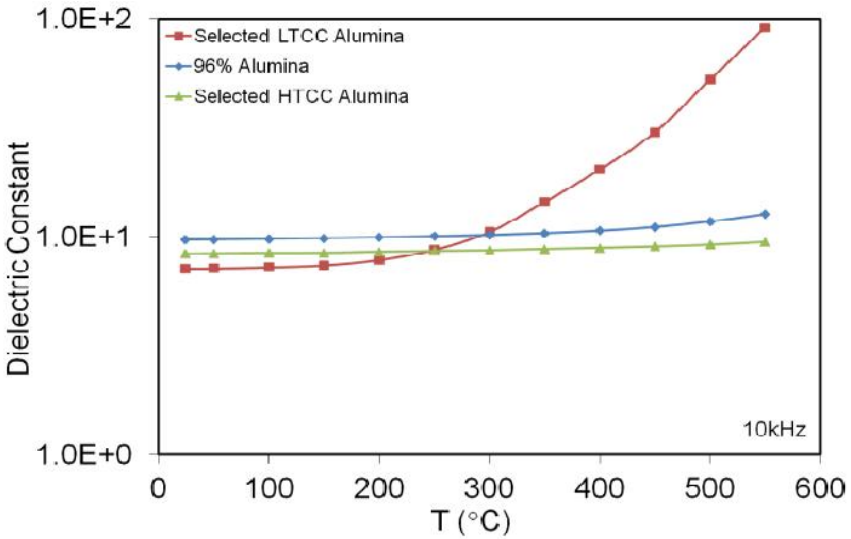
Dielectric constant of LTCC alumina stable below 300°C, increases rapidly with T above 300°C

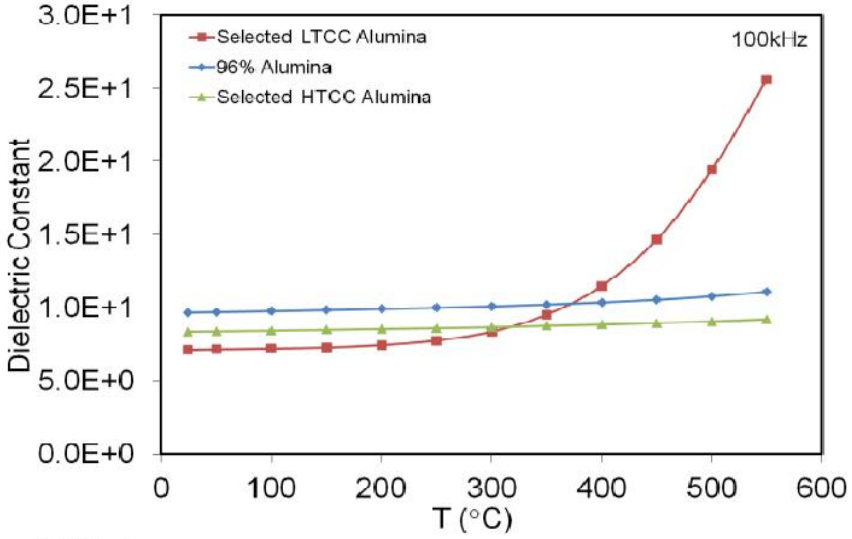
At 120 Hz and 1kHz, it increases by a factor of ~300 and 68, respectively at 550°C

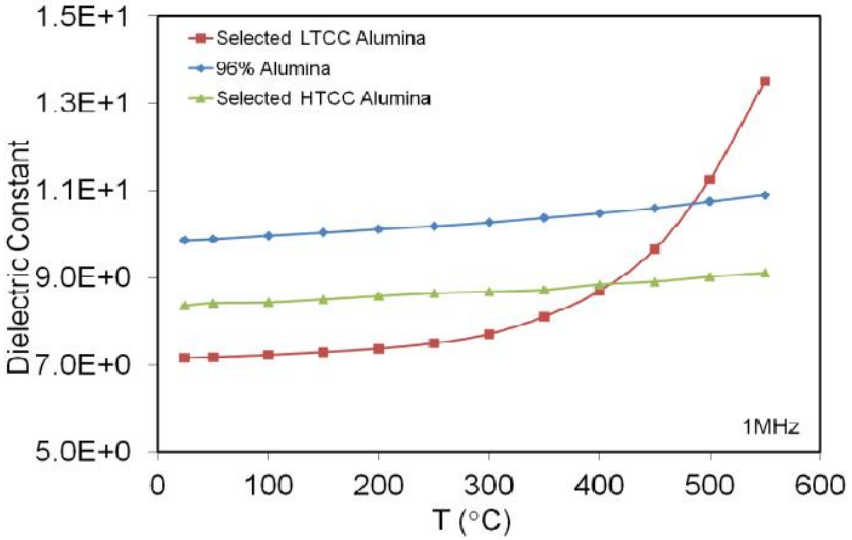
Dielectric constant of HTCC alumina is lower and increases less at 120Hz and 1kHz, compared with 96% alumina

Chen, 2012 HiTEC

Future development of alumina high temperature packaging systems



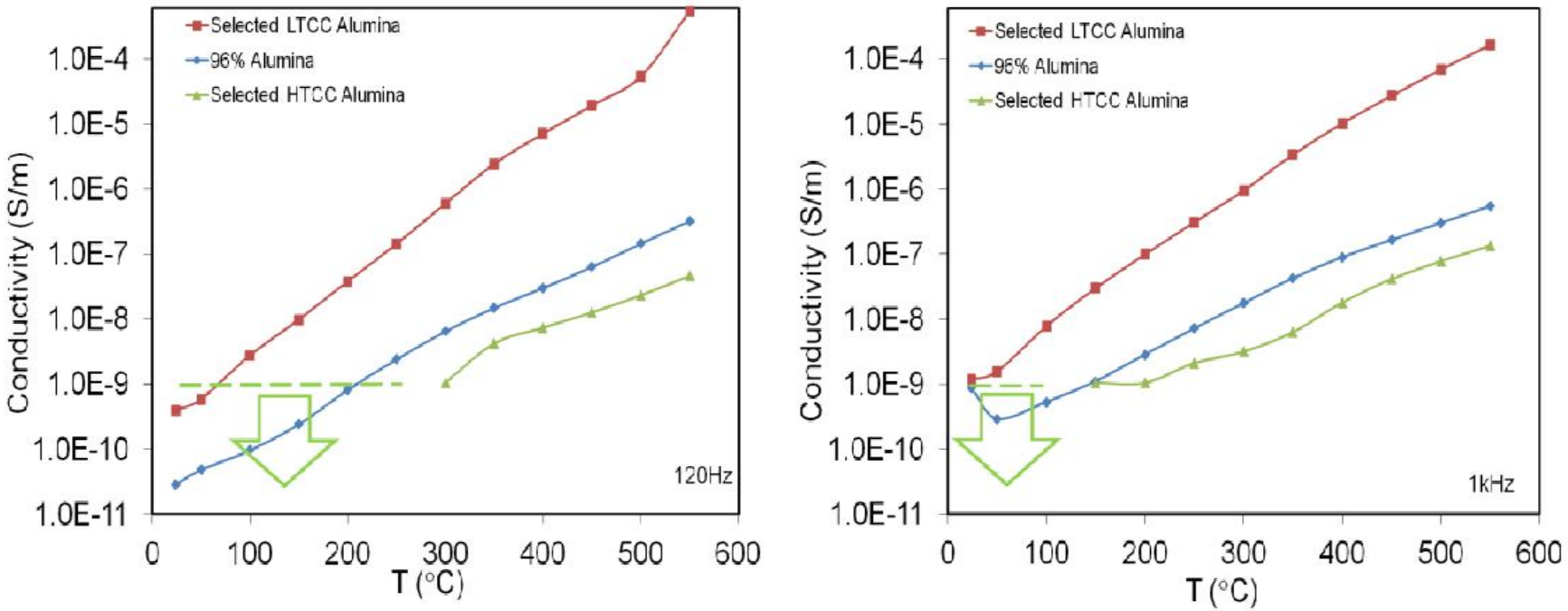




- Dielectric constant of LTCC alumina increases rapidly with T above 300°C
  - At 10 kHz, 100kHz, and 1MHz, it increases by a factor of 13, 3.6, and 2, respectively at 550°C
- Dielectric constant of HTCC alumina is always lower and increases less with T

Chen, 2012 HiTEC

Future development of alumina high temperature packaging systems



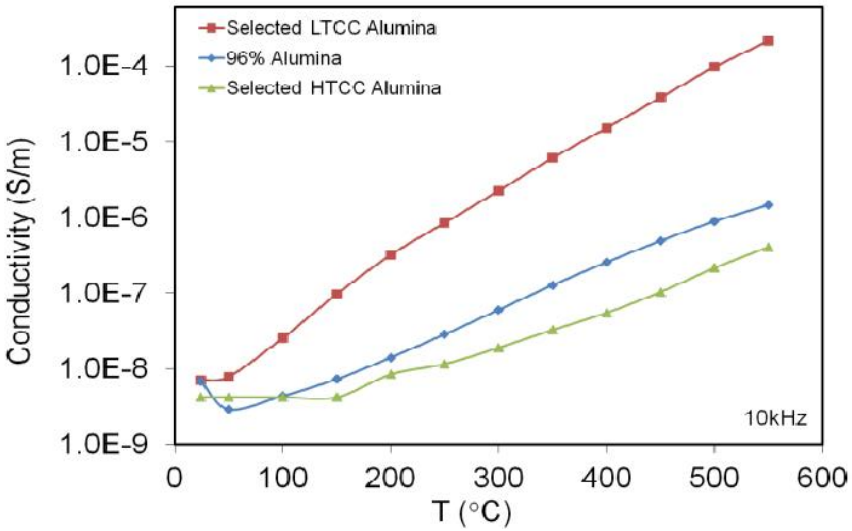
Conductivity of LTCC alumina is higher than 96% alumina and it increases rapidly ~ 300°C at both 120Hz and 1 kHz

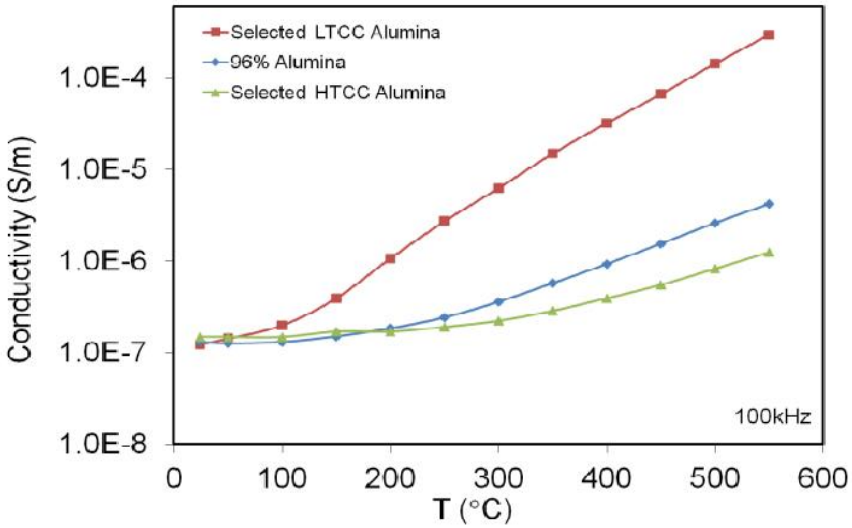
- At 120 Hz and 1kHz, it is four-three orders of magnitude higher compared with 96% alumina at 550°C

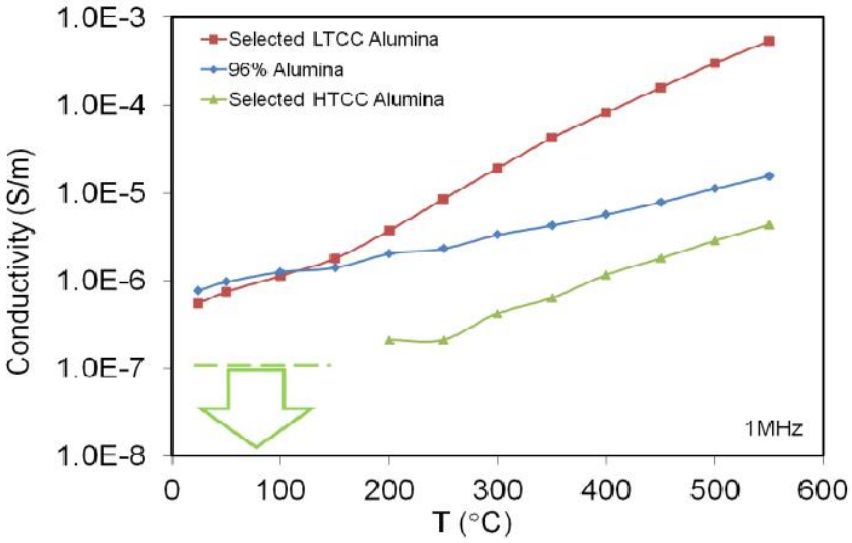
Conductivity of HTCC alumina is ~ an order of magnitude lower compared with 96% alumina at 120Hz and 1kHz at temperatures above 300°C

Chen, 2012 HiTEC

Future development of alumina high temperature packaging systems







- Conductivity of LTCC alumina is higher than 96% alumina and it increases rapidly above ~ 300°C at 10kHz, 100kHz, and 1 MHz
  - At 10 kHz, 100kHz, and 1MHz, it is about two orders of magnitude higher compared with 96% alumina at 550°C
- Conductivity of HTCC alumina is always lower and increases less with T at 10kHz, 100kHz, and 1 MHz

Chen, 2012 HiTEC

Future development of alumina high temperature packaging systems

Compared with 96% alumina

- Dielectric constant and AC conductivity of LTCC alumina increase with T rapidly above 300°C, so this material is more suitable for the temperature range below 350°C
- Dielectric constant of HTCC alumina is slightly lower and it increases less with temperature. AC conductivity of this material is also lower than that of 96% alumina at temperatures above 200°C
  - Dissipation factor of LTCC alumina is always higher at temperatures above 100°C
  - Dissipation factor of HTCC alumina is always lower compared with that of 96% alumina at temperatures above 250°C
- HTCC alumina is also better for hermetic sealing
- Alumina based binders used for HTCC thick-film materials are expected to be thermal dynamically stable in a wide temperature range

Summary

96% alumina substrate and thick-film metallization based packaging systems demonstrated at 500°C

- Alumina and aluminum nitride chip-level packages and PCBs
- Edge-connector in development and test
- Static thermal test of packaged SiC JFET circuits successfully over 10,000 hours at 500°C
- Thermal dynamic test between room temperature and 500°C
- Tested in Shuttle flight, and ISS low earth orbit for eighteen months
- Chip-level packages not fully commercially fabricated

HTCC alumina system

- Selected material characterized and tested at temperatures up to 550°
- Lower parasitic effects
- More suitable for large scale commercialization
- Alumina binder for HTCC alumina systems are expected to be stable at high temperatures
- Further development needed

Thank You Very Much for Your Attention!

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